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Radio Navigation Systems

FOR AVIATION AND MARITIME USE

A Comparative Study

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CONTENTS

2.10. STANDARD-LORAN

(LOng RAnge Navigation)

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1. GENERAL INTRODUCTION

The LORAN system is based on an American proposal made in 1940.[1] At that time it was intended to design such a system for the v.h.f. band. At approximately the same time a similar method was proposed in Great Britain and led to the development of the GEE system operating in the frequency band from 20 to 85 Mc/s. In 1941 tests commenced in the U.S.A. with 8.5 and 2.9 Mc/s: the objective was to increase the range of the ground wave and also to utilize the sky wave reflected from the *E*-layer in order to obtain a long-range navigation system. Already in 1942 ground wave ranges of up to 700 n.m. and sky wave ranges of up to 1400 n.m. across sea were reached with transmitters radiating a peak pulse power of 100 kW. The fixing accuracy obtained was extremely great. Measurements made with frequencies between 1.75 and 1.95 Mc/s produced most favourable results, since at these frequencies the height variation of the reflecting *E*-layer is negligible.

Already in 1943 LORAN was applied for marine navigation and later also for air navigation in the North Atlantic region. In 1944 the SS LORAN system (Skywave Synchronized LORAN) was developed, in which the ground stations were no longer synchronized by ground waves (maximum possible distance 600 n.m.) but by sky waves, and a separation of the interlocked stations of up to 2000 n.m. became possible. Although this method could only be utilized during night-time, and although the accuracy was slightly less than with ground wave operation, it was applied successfully in Europe and Japan during the last year of World War II.

Since then LORAN has been developed further, in particular with regard to accuracy of ground station synchronization and simplification of receiver operation by the application of computers. At present LORAN stations constructed during World War II can be used by ships and aircraft for navigational purposes over a large portion of the globe (Fig. 1).

The frequency band 1750–1950 kc/s used by LORAN lies in the frequency range allocated exclusively to fixed and mobile communication services in Region 1 (Europe, Asia, North Africa).[9] In this region the Iceland–Faeroes–Hebrides LORAN chain is operated. The problem of getting official recognition for the LORAN frequencies was discussed by the Administrative Radio Conferences held in Geneva in 1949[10] and 1951.[11] When the frequency problem of STANDARD-LORAN was discussed again at Geneva in 1959 no world-wide agreement was reached. Thus LORAN navigational transmitters of Region 1 may operate temporarily on the single frequency of 1950 kc/s provided that their operation is regulated by a

special agreement with such administrations whose radio operation would be adversely affected by such LORAN transmitters. In Region 2 the 1800–2000 kc/s frequency band is reserved for Standard-LORAN. In Region 3 the frequencies of 1850 kc/s and 1950 kc/s are reserved for Standard-LORAN.

As early as 1944 attempts were made to transfer the LORAN principle to low frequencies (180 kc/s) in order to obtain greater ranges, especially in the Pacific. These experiments, however, were interrupted after the war. At about the same time it was suggested to synchronize the r.f.-carrier of the pulse transmitters and to apply phase measurement techniques to the receiver in order to increase the measuring accuracy. These proposals were repeated in 1955[2] and led to the development of the LORAN–C system (cf. Chapter 2.11).

2. SYSTEM DESCRIPTION

The Standard-LORAN system is based on the measurement of the time difference between pulses which are radiated synchronously by a pair of transmitters located at a distance of several hundred kilometers (base line). The loci of equal time difference (or distance) are two symmetrical hyperbolae with the transmitters being located in their foci (ambiguous). By delaying the emission from the substation (B) until the pulse from the Master (A) has passed the site of the substation, the hyperbolic position lines become unambiguous, since the pulses of transmitter A cannot be mistaken for pulses of transmitter B. The pulse recurrence of B is synchronized by A. In order to facilitate the indication aboard, the pulses of the B transmitter are delayed by half the time between two pulses from A as received at B.

The signals from a pair of ground stations are displayed on an oscilloscope with two horizontal traces synchronized with half the recurrence rate characteristic for the stations of interest. The leading edges of the pulses constitute the criterion for the time measurement. Several transmitter pairs having different pulse recurrence rates can be accommodated on the same carrier frequency, because irrelevant pulses drift across the stationary display of the correct pulses without impairing the measurement.

Four carrier frequencies between 1750 and 1950 kc/s are used. For the modulation of each carrier three basic pulse recurrence rates are available. Each basic rate is further subdivided into a group of eight by individual frequency differences in the order of a fraction of a cycle per second. The three groups and the individual shifts of their eight frequencies are:

S Group 20 c/s with a shift of 1/25 c/s (S-rate)
L Group 25 c/s with a shift of 1/16 c/s (L-rate)
H Group $33\frac{1}{3}$ c/s with a shift of 1/9 c/s (H-rate)

This arrangement provides for $4 \times 8 \times 3 = 96$ different available channels. The transmitted pulse has a width of 45 μsec and a rise time of 10 μsec.

A measurement is made in the following manner: On the oscilloscope the pulses from the B transmitter (lower line) are placed with their leading edges vertically below those from the A transmitter (upper line); in older equipments the time difference corresponding to this adjustment had to be determined by a special measurement procedure. In more modern receivers

Fig. 1. LORAN Transmitters Station.

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a direct reading is obtained from an electronic counter, which indicates the time difference in three decades. For further details of the transmission and receiving techniques used see refs. 1, 3, 4 and 8 (Fig. 2).

As was mentioned above, a frequency around 2 Mc/s was chosen for Standard-LORAN, since the *E*-layer of the ionosphere reflecting such

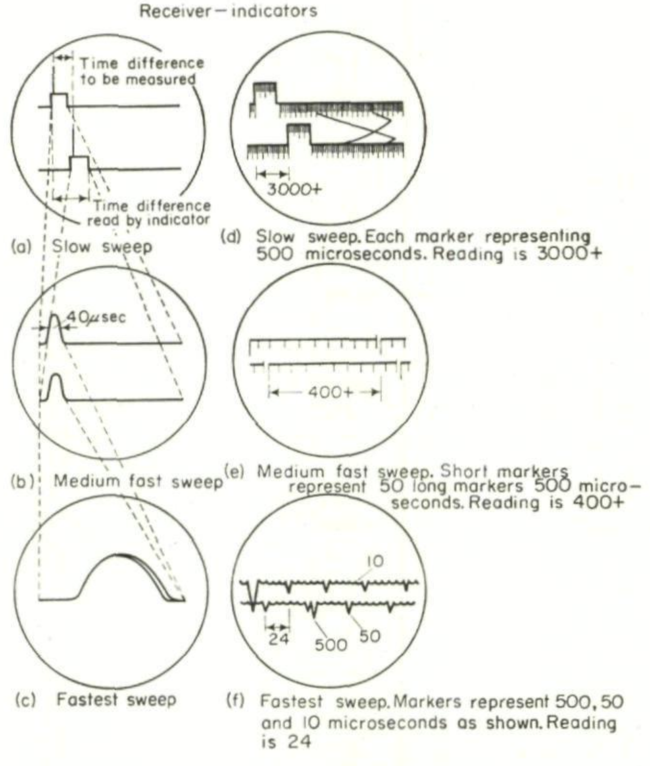

Fig. 2. (a) Slow-trace pattern with signals; (b) medium-trace pattern with signals; (c) fast-trace pattern with signals; (d) slow-trace pattern with 50- *and* 500-*μsec markers, showing time difference of* 3000 *μsec plus approximately* 500 *μsec, (e) medium-trace pattern with* 50- *and* 500-*μsec markers, showing additional time difference of* 400 *μsec plus approximately* 30 *μsec; (f) fast-trace pattern with* 10-, 50-, *and* 500-*μsec markers, showing the time difference of* 24 *μsec. Total time difference is* 3424 *μsec. LORAN-Measuring method*[1]

frequencies maintains a rather constant height ($\pm$ 2.5 km at an altitude of 100 km). Due to international regulations this frequency band is not available for navigation purposes throughout the world; it is reserved, especially in region 1, for marine communication services.

A disadvantage of Standard-LORAN, as far as frequency economy is concerned, is the large frequency spectrum inherent in pulse modulation and the consequently large receiver bandwidth required. This disadvantage is compensated for by the fact that LORAN is the only radio navigation system which, by virtue of the pulse modulation and the cathode-ray tube

display, allows separation of ground wave and sky wave components and, at the same time indicates the reliability of the signal received.

In spite of the small number of carrier frequencies a great number of channels is available due to the different pulse repetition rates, making the narrow frequency band from 1.75–1.95 Mc/s sufficient for a world-wide application of this system.

3. ACCURACY AND RANGE (COVERAGE)

The overall accuracy of LORAN is determined by the geometry of the system, the position of the observer within the service area and by the accuracy of the time measurement. The time measurement accuracy is dependent upon the synchronization of the ground stations, the time difference measurements performed aboard and the propagation conditions. The overall time measurement accuracies can be assumed to be 1–5 μsec (standard deviation), when the ground wave component is used. When the sky wave component is used, the tolerances caused by variable propagation are increased; their magnitude is a function of the time of the day, season, terrestrial latitude, sun spot activity, etc. Thus the standard deviation may be increased by several microseconds. The inaccuracy not exceeded for 95 per cent of the time is therefore said to be 0.2–0.6 per cent of the distance of the receiver from the center of the base line.

The average range (coverage) of the ground wave amounts to 550 n.m. across sea, assuming 100 kW pulse peak power and outside interference fields below 25 μV/m on the receive side.

In equatorial regions the atmospheric noise level is much higher and reduces the range to 400 n.m. during night-time because a useful signal of 250 μV/m is required. In arctic regions a range of 800 n.m. is obtained both at day and at night, with undisturbed ground wave field strength of about 1 μV/m.[1]

According to other publications[4] a range across sea of 700–800 n.m. at an average accuracy of 1.5 n.m. (over land 200–500 n.m.) is obtainable with ground waves during daytime. The corresponding values for night operation and utilization of the sky wave are: 1400 n.m. over sea and over land with an accuracy of 5 n.m.

The ground wave range is increased by 100–200 n.m. with a peak pulse power of 1000 kW.[4]

The detailed computation of the error circle is given in Part 3 of this report: " Range (Coverage) and Accuracy of Radio Navigation Systems ".

4. NAVIGATIONAL AND OPERATIONAL CONSIDERATIONS

The radio coordinates supplied by LORAN are hyperbolic lines of position whose ordinal number corresponds to the value of the time difference measured on the receiver. Normally each time a fix is required a new individual measurement has to be taken. There are, however, also automatic continuous indicators available. Such indicators follow automatically the changes in time difference readings caused by the craft moving relative to a pair of stations to which the receiver is tuned. The instantaneous values are indicated directly.[7] The geographical position of the radio coordinates is obtained from special charts provided with a suitable superimposed

hyperbolic grid system. When no special chart is available the radio coordinates indicated can be used for navigational purposes only when a hyperbolic line of position accidentally would coincide with the planned course.

Operation of the equipment is relatively simple when the ground wave clearly predominates. However, profound experience is required for recognizing the first incident sky wave at long ranges and in particular for distinguishing ground waves from sky waves within the intermediate regoin and for superimposing both leading edges, which is so important. Errors in allocating corresponding leading edges (ground wave and first hop sky wave, or first and second hop sky wave respectively) can be reduced by prolonged observation of the cathode-ray tube screen.

When the received signals are observed on the cathode-ray tube, position finding can be performed up to a signal-to-noise ratio of approximately 2 : 1.

5. GROUND STATIONS AND AIRBORNE (SHIPBORNE) EQUIPMENT

Ground Stations

A Standard-LORAN chain used for navigational purposes consists of at least three transmitting stations located at a distance from each other of approximately 200–400 n.m. The peak pulse power of the transmitters is 100 kW, the line load is approximately 15 kVA (30 kVA at a peak pulse power of 1000 kW). The transmitters are equipped with synchronizing facility and monitor equipment.[4] The central (master) transmitter of such a chain radiates two pulse groups by means of which the two slaves are synchronized on the same carrier with one pulse group each.

There are also chains consisting of two pairs of stations of Masters and Slaves.

The transmitters are operated manually; automatic synchronization of the Slaves is being developed.

Site requirements: approximately $(200 \times 200)\ m^2$ per transmitter station.

Antenna: either of the T-type, 30 m high, or steel towers 33 m or 100 m high, respectively.

Airborne (Shipborne) Equipment

Special receivers with four fixed channels (1750, 1850, 1900 and 1950 kc/s); bandwidth 40 kc/s; cathode-ray tube and facility for time difference measurement; since recently, electronic counters are available. Weight of a modern marine receiver Model LR 8803 (RCA) approximately 50 kg, price in Germany approximately 15,000 DM.

Aboard aircraft Standard-LORAN receivers of the war years are still used extensively. An example of a modern airborne receiver is the EDO receiver (see Table 4.3).

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